NUMERICAL REANALYSIS THROUGH PROPORTIONAL DIFFERENCES

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THESIS

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by

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through
Proportional Differences

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ABSTRACT

A new approach to numerical analysis is presented. Instead of providing conventional data one essentially prescribes the desired pattern and the analysis is performed through proportional differences.

If satellite or other data indicate a synoptic system in a numerical analysis should be reanalyzed, a three-dimensional manual analysis is performed. Particular attention is given to the adjustment of the location and orientation of the synoptic pattern. No changes are permitted on the borders of the finite area containing the synoptic system.

Orientation axes for the patterns of the numerical and manual analyses are defined by sets of key points. Using the space difference between these orientation axes, the boundaries and the amount of development specified at the key points this scheme guarantees a reanalysis which smoothly blends with the original analysis and retains the new location and orientation of the synoptic system.

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I. INTRODUCTION

Satellites have been providing ever increasingly useful data to the meteorologist for synoptic scale analysis of weather patterns. Some of the numerous studies which introduce the terminology and interpretations of synoptic-scale cloud patterns as viewed from satellites are references [1], [2], [3], [4], [5], and [6] for video photographs and references [1] and [7] for infrared imagery interpretation. However, the major problem has been to determine how satellite observations can be assimilated with conventional data in a numerical analysis scheme, be it infrared or video in photographic format or Satellite Infrared Spectrometer (SIRS) data. SIRS data is not a big problem in numerical analysis programs because the derived heights and temperatures are essentially conventional data, as indicated in [8]. The problems of numerical application of video and infrared data from satellite observations are explained in reference [9]. One of the earliest attempts to numerically integrate the satellite data with conventional data was to do it indirectly, through the use of the relative vorticity field, as given in [10]. A more objective way of relating the synoptic-scale cloud pattern to the relative vorticity field is described in [11], [12], and [13]. This relative vorticity approach is fundamentally that of Fjørtoft [14] where the total height field is the sum of the mean-height field and the disturbance or relative vorticity field.

Another early approach was to estimate wind direction from the "blow off" of the cirrus plumes of cumulonimbus clouds as observed in the video data of TIROS and ESSA satellites. The spin-scan cloud camera of the Applications Technology Satellites (ATS) can provide video information as often as every 20 minutes. The ATS video data may be converted into film loops to provide a means of estimating wind speed and direction from cloud motion, as explained in [15] and [16].

Presently the operational use of inferred data from video and infrared imagery requires the use of "bogus" data in the analysis program. Bogus data is the name often applied to satellite and other non-conventionally observed data when these values have been coded in the format of conventional synoptic reports for use in a numerical analysis program. Most of these bogus data are taken from points within an area which has been manually reanalyzed in order to provide a more reasonable relationship between the mass field and the observed cloud patterns. The bogus data are combined with the conventional and SIRS data for a numerical reanalysis of the entire area, usually the whole Northern Hemisphere, by the standard operational analysis program.

Mantei and Workman [17] found that preparation of numerous bogus data values is a laborious process and that the determination of the location of bogus data points (when working with a fixed maximum number of bogus data soundings) usually requires several relocations and recomputations to

finally arrive at the desired synoptic scaled patterns of isolines when using a conventional numerical analysis program.

Another solution to the problem of numerical reanalysis in sparse data areas is a numerical scheme based on proportional differences suggested by Hamilton [18]. In this scheme a finite area is delineated for reanalysis with no changes in the initial values of the parameters permitted on the borders. Within this finite area a meteorologist has performed a manual reanalysis at the levels required (such as, 1000 mb, 500 mb and 300/200 mb) to establish the best spacial and time continuity of all the data available within the area. The information available is in the form of conventional data (ship, rawinsonde, aircraft, etc.), inferred satellite data (synoptic interpretations of satellite data) and derived satellite data (solutions of statistical regression equations for heights of a constant pressure surface [13], and heights and temperatures from SIRS data, and wind velocities from ATS data).

The basis of this study is the fact that the most reliable information which can be inferred from satellite imagery is the location of synoptic scaled systems, such as cyclones, troughs, ridges, jet streams and anticyclones. Based on the location of these synoptic scaled systems and derived satellite data, manual improvements of numerical analyses may be easily accomplished in sparse data areas.

As indicated earlier, this may be required at three different levels within a given finite area of the numerical grid.

These manual improvements may be incorporated numerically when reanalysis is accomplished through proportional differences. The only information required by the computer is the location of the finite area, the location of key points within the initial numerical analysis and within the manual reanalysis, and the amount of parameter (height, temperature, etc.) changes desired at these key points. Key points are those minimum number of points which delineate the synoptic pattern within these two analyses. For example, if the synoptic feature to be relocated is a trough, the key points locate the axis of the trough (as simulated by straight line segments) within the same finite area of both the initial numerical analysis and the manual reanalysis. If the synoptic feature is a cyclone, the key points locate the center and possibly delineate two axes for pattern orientation.

The method of this analysis scheme is to relocate the values of grid points of the initial numerical analysis based on the difference in space between the axes described by key points in the two analyses and proportion this difference across the finite area, such that there is no displacement of the values on the borders. Then apply a four-point Lagrange interpolation scheme to the field of displaced values to establish new values at the grid points of the numerical grid. The amount of development specified at one or more of the key

points is proportioned along the axes and then across the entire field. The final grid-point values are the sum of the interpolated values and the development values.

A unique feature of this analysis scheme is that the desired location and orientation of synoptic features is guaranteed to appear in the numerical reanalysis as determined from the inferred satellite data, the derived satellite data and all the available conventional data.

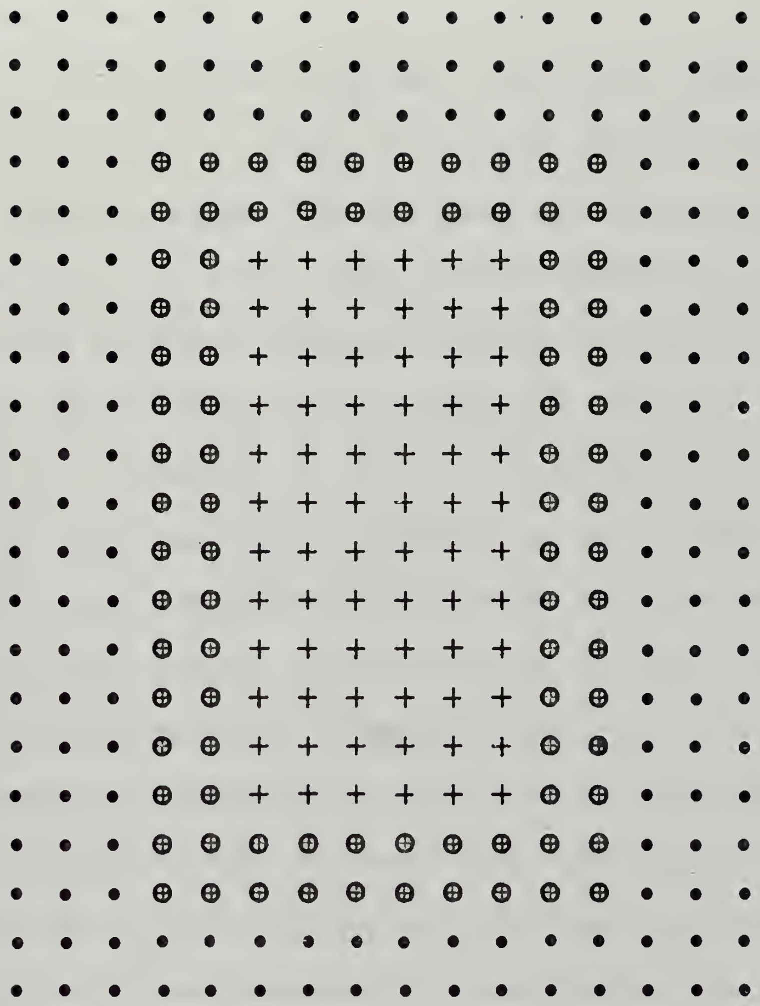
II. PROPORTIONAL DIFFERENCES SCHEME

A. BACKGROUND

As suggested in the introduction, a synoptic-scaled system within a sparse data area may require reanalysis based on conventional data, inferred data from satellite observations, satellite-derived data or any combination of these three for one or more levels. A manual reanalysis is performed at the required levels to establish the best agreement with all the available information, and to ensure vertical and time continuity.

The boundaries of the reanalyzed synoptic feature (cyclone, anticyclone, trough, ridge, or jet stream) are delineated by grid points of the operational numerical grid for the numerical reanalysis using proportional differences. For ease of computation in this research rectangular bounded areas are used, but this is not necessary as long as the border is defined with grid points of the numerical grid.

To ensure a smooth blending with the surrounding areas the width of the borders are chosen to be one grid length. Figure 1 schematically represents a field of interior grid point values chosen for reanalysis. The interior values are surrounded by a double border of values which are extracted from the total field of grid point values of the initial numerical analysis. These border grid point values are not permitted to change during the numerical reanalysis of this finite area. The initial fields may be any synoptic



• exterior grid point
⊕ border grid point
+ interior grid point

Figure 1. SCHEMATIC OF GRID POINT FIELD

parameter, but in this study the fields used are height and temperature on constant pressure surfaces.

B. ORIENTATION AXES

Within the bounded grid are one or two axes which are defined by points in order to orient and re-orient features on the synoptic scale. These axes are in the general directions of the i and j axes of the numerical grid. If an axis of the synoptic feature is more aligned with the i-axis than the j-axis of the numerical grid the orientation axis will be referred to as an i-directed axis, and similarly for an axis oriented primarily in the j-axis direction. These two axes can probably describe even the most complex patterns which retain synoptic-scale features only. Each axis is chosen so that it extends from one side of the interior grid to the opposite side and is described by a minimum number of key points. The only key points which are required by this scheme are the two end points of the axis and any points between the end points where the axis changes direction. The axes are defined for both the initial numerically-analyzed pattern and the manually reanalyzed pattern. The axes of the initial numerical analysis are referred to as the analyzed axes and the axes of the manual reanalysis are referred to as the observed axes in this report.

If a pattern is to be translated in the i-direction of the numerical grid, both an analyzed and an observed j-directed axis must be specified for the translation to be

accomplished numerically. Likewise, an adjustment of the analyzed pattern in the j-direction of the numerical grid requires both an analyzed and an observed i-oriented axis be specified. Translation in an oblique direction of the numerical grid requires both an i and j orientation axis be defined for the analyzed and the observed patterns. If no translation is desired for a portion of the pattern, the analyzed and observed axes are coincident. Figure 2 is a graphical representation of a simple translation in either the i or j direction. In the figure the analyzed axis is the solid line and the observed axis is the dashed line. The arrows indicate the translation is parallel to an axis of the numerical grid.

C. PROPORTIONAL DIFFERENCES

Within the specified bounded area no changes to the initial fields are permitted on the borders while adjustments of the height and temperature fields are being accomplished in the interior relative to the axes described above. This suggests proportioning the magnitude of the adjustment along a row (j constant) or a column (i constant) of grid points of the numerical grid with the maximum at the point of greatest adjustment to no change at the corresponding border grid points. This proportioning process is performed along an i-axis (row) for translation in the i-direction and along a j-axis (column) for translation in the j-direction. Translation in an oblique

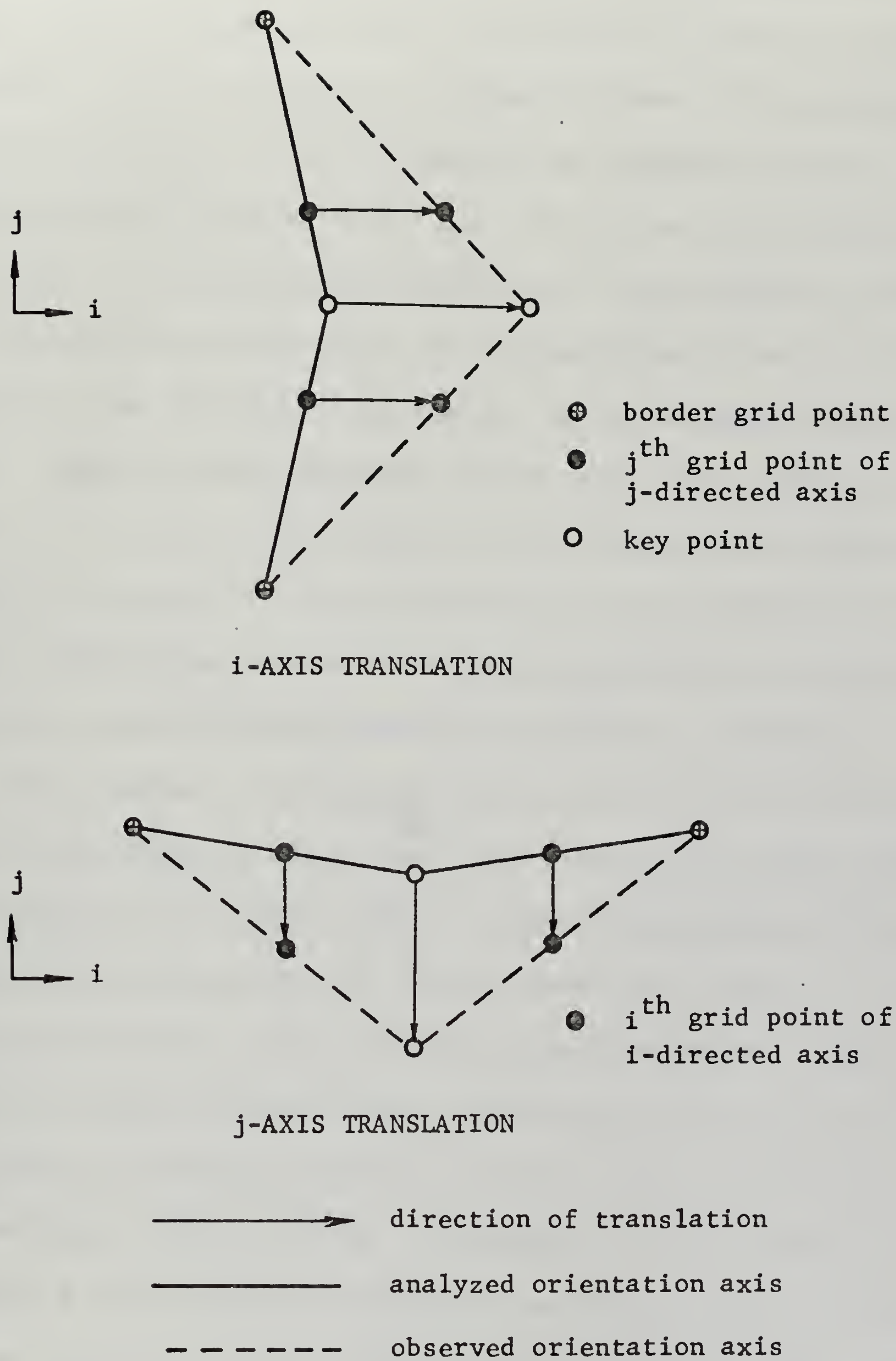


Figure 2. SCHEMATIC OF SIMPLE TRANSLATION

direction relative to the numerical grid is carried out in two steps, first in the i-direction and then in the j-direction, or vice versa, in order to keep the program simple and efficient with respect to computer time. Figure 3 is a schematic representation of the two step translation for motion in an oblique direction. The diagram illustrates the intermediate axes which are determined numerically in order for the oblique translation to be accomplished in two steps. That is, the program calculates the location of the key points of the intermediate axes based on the position of the key points of both the analyzed and observed axes. In this particular scheme the translation in the i-direction is always accomplished first in an oblique movement. Therefore, the program calculates the location of the key points of the intermediate axes such that after an i-axis shift of the analyzed key points only a j-axis adjustment is required to place the key points of the intermediate axes in coincidence with the key points of the observed axes. This scheme treats the key points of the j-directed axis of the intermediate axis as though they are the key points of a j-directed observed axis and performs a standard i-axis shift and determines a new field of values at each grid point of the interior portion of the finite area numerical grid. Using the key points of the i-directed axis of the intermediate axis as though they are the key points of an i-directed analyzed axis the program then performs a standard j-axis adjustment. A final determination of the grid-point values

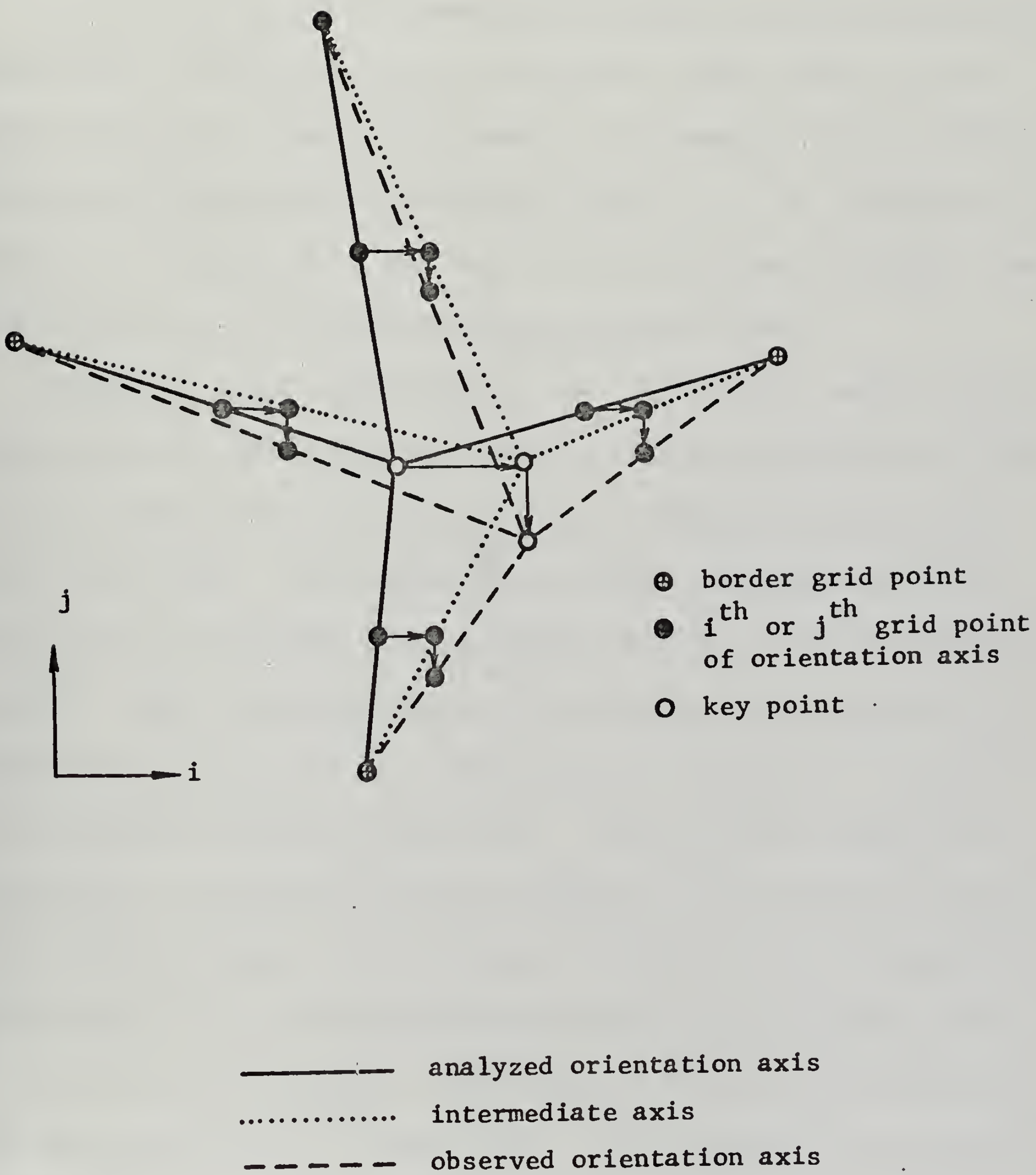


Figure 3. SCHEMATIC OF OBLIQUE TRANSLATION

resulting from an oblique translation is calculated based on the new field of values obtained from the previous i-axis shift. In Figure 3 the solid lines are the analyzed axes, the dotted lines are the intermediate axes, and the dashed lines are the observed axes.

Prior to numerical reanalysis using proportional differences, a specification is made for each field to be modified of the number of axes, the number of key points defining these axes, the motion type (i, j or oblique), the amount of development desired (to be discussed later), and the location of the boundaries and key points.

For an i-axis translation, two j-directed axes must be calculated by the program from the given key points of the initial numerically-analyzed field and the manually reanalyzed field. The orientation axes are assumed to be composed of straight-line segments between the defining key points. Thus the equations of straight-line segments between the key points are determined numerically for both the analyzed and observed axes. Using these equations, i-values are calculated by the computer along both orientation axes for each row (integer j-value) of the numerical analysis grid. The difference between these calculated i-values is the maximum displacement between the analyzed and observed axes for each row. The maximum displacement for each row is then linearly proportioned along the row from the point of maximum displacement to the locations of no displacement, that is, the two opposite border points.

Figure 4 is a graphical representation of this proportioning process. In the figure the solid line is the analyzed axis and the dashed line the observed axis. Illustrated in Figure 4 are the symbolic form of the proportioning equation, the amount of translation (d), the definition of the symbols used in the equation and an illustration of these symbols.

D. INTERPOLATION SCHEME FOR TRANSLATED VALUES

Once the new location of each initial interior grid value (height or temperature) is determined a new value for each grid point of the numerical grid must be computed. When a single shift is performed, this is accomplished with the four-point Lagrange interpolation scheme [19] applied only to the initial values of the grid points. This approach was judged to give the best results after independent testing using only initial values and a mixture of initial and interpolated values in linear and three, four, and five-point Lagrange interpolation schemes. Figure 5 is an illustration of the four-point Lagrange interpolation scheme. The orientation of the grid points presented may be either along a row or a column of the numerical grid. If an i-axis adjustment is being accomplished, the interpolation is stepped along each row with the i-th gridpoint always between the second and third known values of the parameter being interpolated. Once new values are interpolated for each interior grid point of a row or column

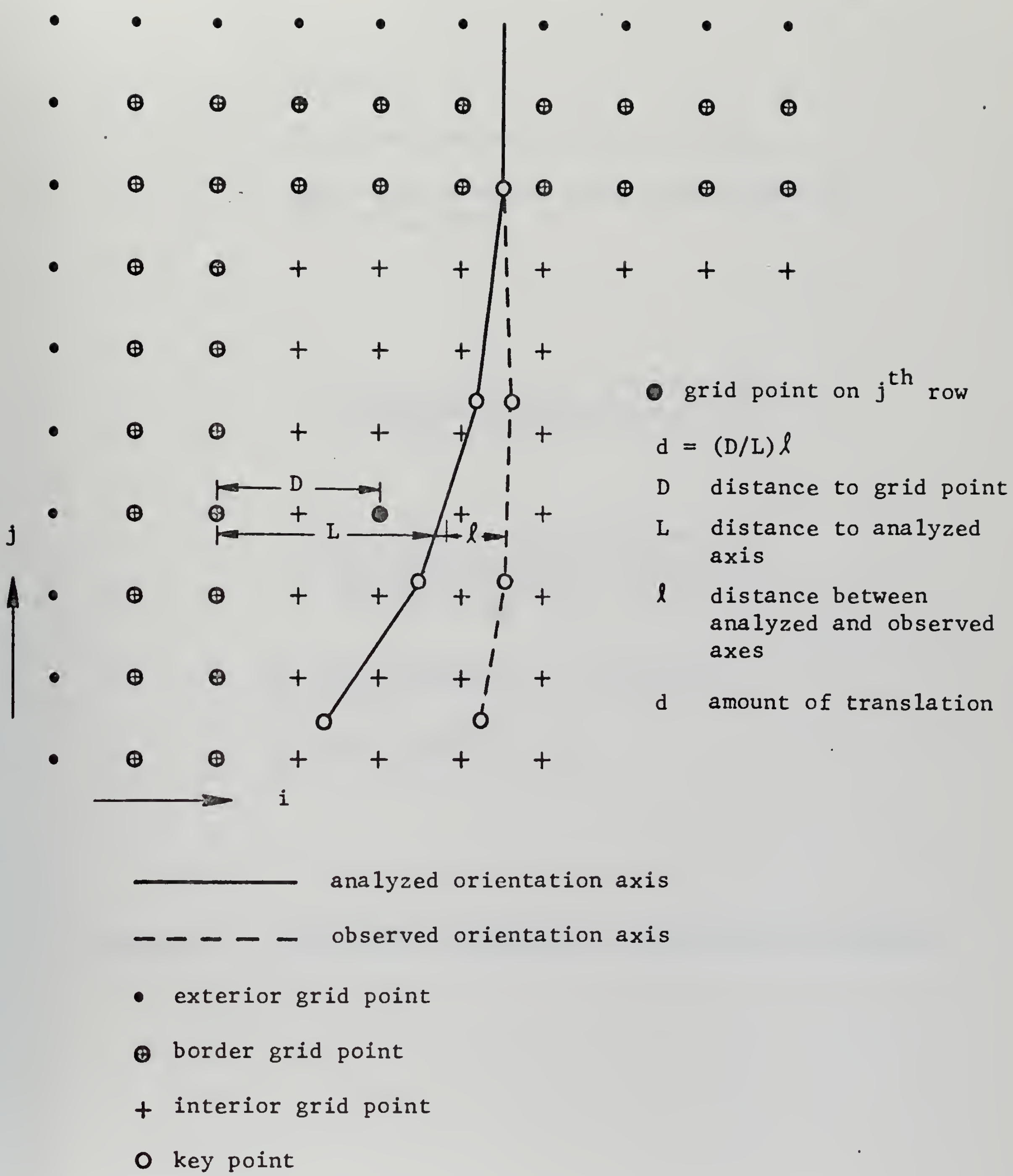


Figure 4. SCHEMATIC OF PROPORTIONING PROCESS

$$
\begin{array}{ccccccccc}
+\ \cdot & & + & \cdot & + & \cdot & + & & +\ \cdot \\
Q_1 & & & Q_2 & i & Q_3 & & & Q_4
\end{array}
$$

+ grid point

• displaced position of grid value Q_n

i grid point to which interpolated value of Q will be assigned

$$
Q_i = Q_1 \left[\frac{(x_i - x_2)(x_i - x_3)(x_i - x_4)}{(x_1 - x_2)(x_1 - x_3)(x_1 - x_4)} \right] + \cdots +
$$

$$
Q_4 \left[\frac{(x_i - x_1)(x_i - x_2)(x_i - x_3)}{(x_4 - x_1)(x_4 - x_2)(x_4 - x_3)} \right]
$$

x_i grid location of i^{th} grid point

x_n grid location of Q_n

Figure 5. FOUR-POINT LAGRANGE INTERPOLATION SCHEME

the interpolation scheme is applied to the next row or column of the grid. In this manner new values of a particular parameter, such as height or temperature, are determined over the entire grid within the double bordering grid points. In addition, this approach guarantees a smooth blending of the numerically-reanalyzed field with the surrounding initial numerically-analyzed field.

E. INTERPOLATION SCHEMES FOR VALUES OF DEVELOPMENT

Changes in height or temperature at the grid points due to actual development within the sparse conventional data area and those changes in height or temperature required to adjust the changes occurring at the grid points because of the translation of the synoptic system will be summed and called developmental changes, as opposed to those changes resulting from the translation required for proper positioning. Therefore, the value of development at any given location within the grid is the value of the parameter in the observed (manual analysis) field minus the new value of the parameter created by translating the analyzed (initial numerical analysis) field. Note that with this particular numerical reanalysis scheme the value of all key points on a single orientation axis are not changed during a simple translation. Thus the value of development at each key point on the observed orientation axis is the value of the key point in the observed field minus the value of the corresponding key point of the

[illegible]

analyzed axis in the initial field. With this scheme the value of development need be specified only at one or more of the key points on the observed orientation axis.

Developmental changes are determined numerically along the observed axes with a linear interpolation scheme applied between the values of development given at the key points defining the observed axis. No development is permitted on the boundaries. If desired, this program will provide interpolated values at the defining key points when at least one value of development is initially specified.

A field of development values is determined by linearly proportioning the values calculated on the orientation axis over a row or column to the borders. That is, an i-axis shift results in a row-wise linear proportioning from the j-directed observed orientation axis to provide a field of development values. Likewise, a j-axis shift results in a columnwise linear proportioning from the i-directed axis.

The development field computations are more complex when a field is translated in only one direction but has two observed axes, one in the i and the other in the j direction; or a field is translated obliquely, which by definition requires two observed axes. In such cases the values of development along the j-directed observed axis are calculated but are not proportioned into a field during the i-axis translation of the program. When proceeding

through the j-axis translation of the program a field of development values based on the distribution of development changes along the i-directed axis is determined. Figure 6 schematically illustrates how the development field based on the i-directed observed axis is obtained. The dashed line represents the j-directed observed axis extending between the key points of this axis. Note that for simplicity the end points of the axes, which are key points, are not illustrated on the borders.

The previously calculated values of development along the j-directed axis will most likely not agree with those interpolated from the field of development values based on the i-directed axis. However, the development values calculated on both the j-directed axis and the i-directed axis must be retained in the final field of development. Therefore, the field of development based on the i-oriented axis must be modified to smoothly incorporate the values on the j-oriented axis. To accomplish this smooth blending of development values specified along both the i and j observed axes, a four-point Lagrange interpolation scheme is used to compute the value of development from the field of development values based on the i-oriented axis for each row value (integer j value) of the j-oriented axis. A difference value is computed between this interpolated value and the previously computed value of development along the j-directed axis for each row. These difference values are then linearly proportioned along each row to the border or

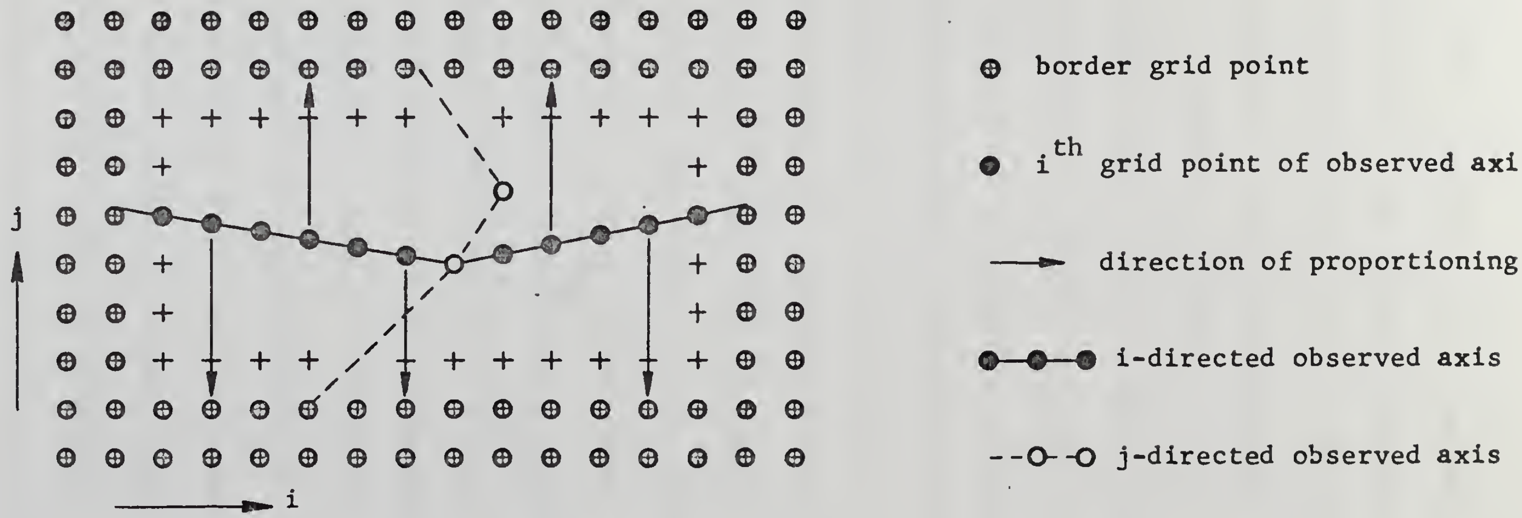


Figure 6. DEVELOPMENT FIELD BASED ON THE i-AXIS

to the i-directed observed axis; whichever is closest to the j-directed axis. By definition the difference values along the i-oriented axis and on the borders must be zero. When the process is carried out for all the rows a field of development difference values is generated. The development difference field and the development field based on the i-directed axis are added together to arrive at the final development field. Figure 7 illustrates the proportioning of the development difference values from the j-oriented observed axis to the border or the i-oriented observed axis. Note the existence of "shadow zones" between the i-oriented axis and the borders. These shadow zones are areas of zero difference which is the correct value of difference within these areas.

The final field of numerically reanalyzed values within the finite area is obtained by adding the modified field based on the translation of the synoptic pattern and the field of development changes. This combined approach guarantees the location and orientation of the synoptic feature to be as indicated by all the available information, and particularly the satellite imagery data. This numerical reanalysis program provides a reasonable estimate of the values of conventional parameters at each grid point within a sparse conventional data area.

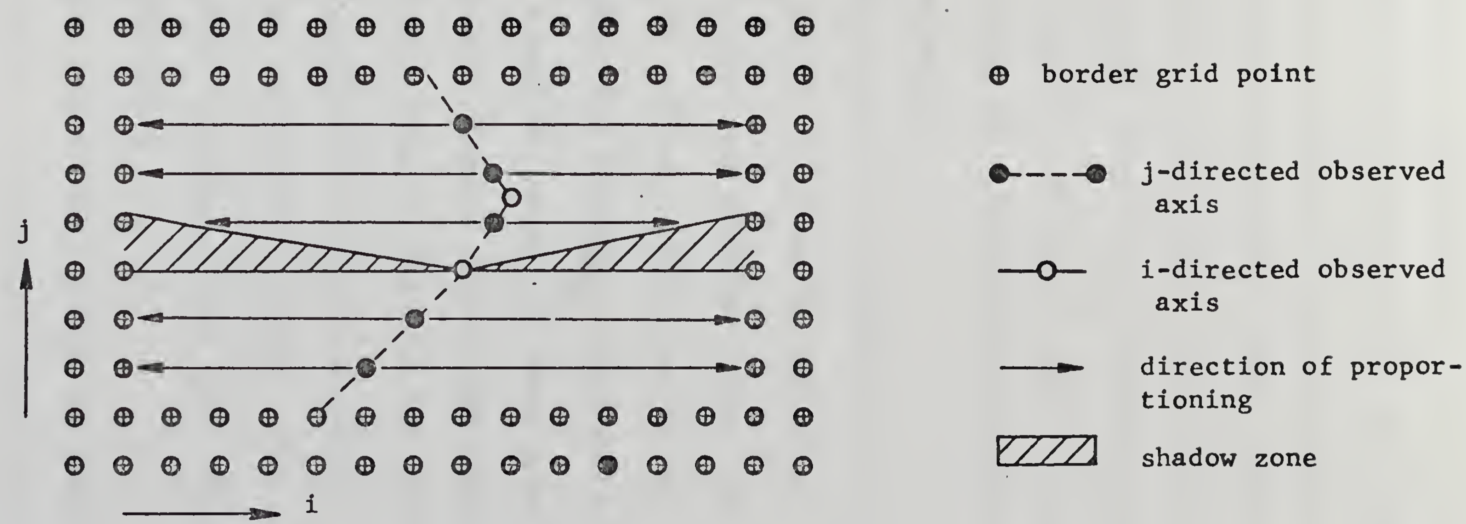


Figure 7. DEVELOPMENT DIFFERENCE FIELD

F. METEOROLOGICAL CONSTRAINTS

Initial and reanalyzed fields are checked for vertical continuity and conformance with dynamic constraints. The first part of the continuity check compares the mean virtual temperature of the layer with the arithmetic mean value of the layer using the temperatures at the top and bottom of the layer. The mean virtual temperature is determined with the 500-1000 mb thickness values used in the hypsometric equation.

Observations from 12 November 1971 to 31 March 1972 of the daily Oakland, California, soundings have shown that the average difference between these two mean temperatures is about 2.61°C. This difference in the Oakland soundings should be comparable with the inequality of these mean temperatures in a marine sounding over a mid-latitude oceanic sparse data area. Therefore, a difference of 2.0°K between the mean virtual temperature and the arithmetic mean temperature is considered within tolerance for the first part of the vertical continuity check. The second part of the vertical continuity check tests for the existence of superadiabatic lapse rates.

The dynamic constraint check calculates absolute geostrophic vorticity. Any value less than 1.0×10^{-6} sec^{-1} is considered to indicate that the relative vorticity is too negative.

These checks were used to locate errors while testing this scheme. The conventional numerical analysis schemes

in operational use have their own checks which ensure proper vertical consistency and dynamic constraints of the initial fields. Prior to using this scheme as presently programmed, the key points should be manually checked for hydrostatic and dynamic constraints. If the initial numerical analysis fields and the key points are dynamically and hydrostatically consistent then this proportional scheme should ensure that the final reanalyzed fields will remain meteorologically constrained. This has been observed to be the case during the preliminary testing of this approach to numerical reanalysis.

If for some reason the reanalyzed fields did not pass these or other analysis checks, the new grid-point values within the bounded area and the initial grid-point values outside the bounded area could be recycled through the conventional numerical analysis program as observed synoptic values in order to eliminate analysis discrepancies.

III. RESULTS

In the initial phase of this research the various features of the program were extensively evaluated to ensure proper performance. Troughs and ridges (ridges are treated identically to troughs in this program) were tested first to ensure proper movement in both the positive and negative i and j directions. The same was done for cyclones and anticyclones (again, anticyclones are treated the same way as cyclones in this approach to numerical reanalysis). After these features could be moved reliably along an i or j-directed axis the programming for oblique movement of systems was tested. Finally the development subroutine was evaluated for proper performance.

In order to provide a good test of this numerical reanalysis scheme the numerically analyzed fields of height and temperature, twelve hours apart, over North America and North Pacific Ocean are used to establish initial (Numerical Analysis) and observed (Manual Reanalysis) fields. Therefore, the heights and temperatures within the finite area for reanalysis have undergone a twelve-hour change. A manual reanalysis is then performed to incorporate the major twelve-hour changes of the synoptic system and to blend these changes into a no-change boundary around the associated finite area. Thus, the changes near the center of the reanalysis areas illustrated in Figure 8 through 17 simulate the amount of change of height or temperature

which would probably be encountered in the operational use of this program. All isolines illustrated in Figures 8 through 17 are delineated on the basis of a linear analysis computer program using a printer for output. The double borders of the finite area of this scheme are delineated in the figures for ease of orientation and reference.

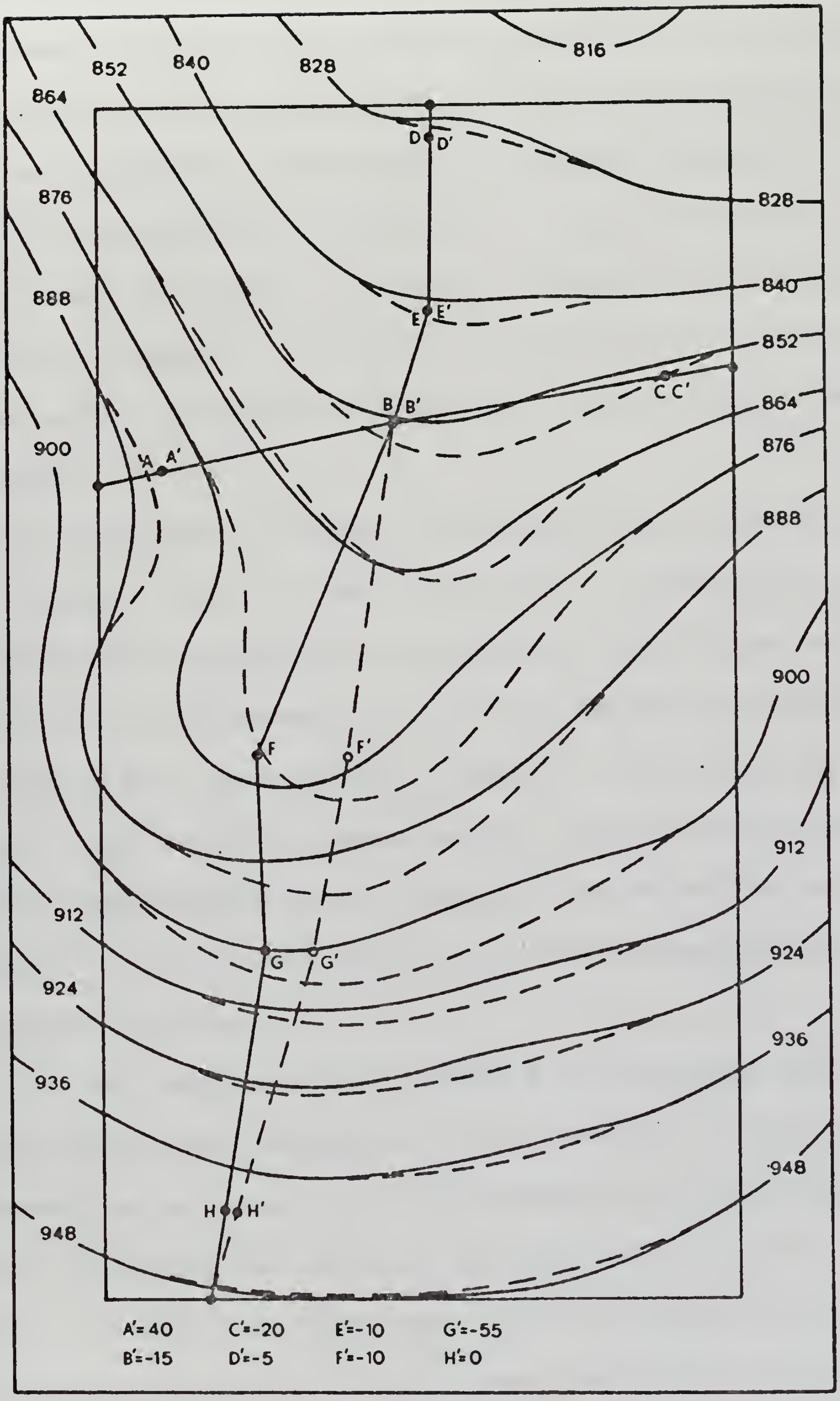
The grid-point values of height and temperature are interpolated from the analyzed charts of the National Weather Service. The grid spacing used in this scheme is about 381 km at 60N, which is the same spacing currently used in the operational programs of the Fleet Numerical Weather Central and the National Weather Service. A grid size of 10 by 16, about 1,850 by 3,080 n mi, is illustrated in Figures 8 through 17. This provides an area of about 1,440 by 2,670 n mi for reanalysis. The computer time required for the reanalysis of the 500 mb and 1000 mb height and temperature fields shown in Figures 10 through 17 is about 1 minute on an IBM 360-67, with a total core storage of about 175K.

To further the understanding of this method of numerical reanalysis, Figure 8 will be discussed in a step-by-step manner. The continuous contours, in this case the isohypses of the 300 mb map, represent the initial numerical analysis over a given area. Based on additional data, probably from a satellite, a meteorologist working in a quality control section determines that this initial analysis is in error and requires reanalysis. As a first step, he performs a

manual reanalysis at the levels required for spacial continuity and establishes the boundaries of the finite area of numerical reanalysis. The dashed contours of Figure 8 simulate this manual reanalysis, but in this specific example these represent the twelve-hour change of the 300 mb surface, near the center of the figure, as determined by the succeeding National Meteorological Center's operational numerical analysis over North America.

The second step in using this numerical reanalysis scheme is the determination of orientation axes, defined by the choice of key points, which may or may not be trough and ridge axes. In Figure 8 neither of the orientation axes are trough or ridge axes.

It is noted that these orientation axes are i-directed and/or j-directed axes and must start on one border and terminate on the opposite border. The end key points on the borders must be the same for the initial numerical analysis and the manual reanalysis (observed field) if the value of the parameter being analyzed is not nearly constant along the border between the two end points. Along an orientation axis are a chosen number of other key points as determined by the complexity of the axis. This complexity is determined by the amount of reorientation required and the degree of gradient control desired. However, the number of key points on an analysis axis must be the same as that on the corresponding observed axis.



——— NUMERICAL ANALYSIS ------MANUAL REANALYSIS

Figure 8. 300 MB HEIGHTS: NUMERICAL ANALYSIS AND MANUAL REANALYSIS

It should be noted that in cases of simple translation of closed systems only a few key points are required. The center and the end points of each axis is generally all that are required. In a case of uniform filling or deepening of a translated, closed system only the center value of development is needed. If only filling or deepening of a system is required, and this is generally an evenly distributed value, then only a central value of development is required.

Any extensive pattern reorientation and modification will usually require many key points. These points will be required as anchors for pattern translations and development. A good example of such an extensive modification is illustrated in Figures 16 and 17. Fine control of trough locations or gradients may require many key points on the axes, depending on the axis orientation, as contrasted to only a few points for coarse control or rather straight troughs.

The depiction of the analyzed orientation axes, the continuous lines through the lettered key points, and the observed orientation axes, the dashed lines through the primed lettered key points, of Figure 8, indicate a translation in only one direction. In this case the positive i direction and then only between key point B/B' and the lower, common border key point. That is, when corresponding key points on the analyzed and observed orientation

axes are coincident there can be no translation. And between two coincident points the orientation axes are superimposed upon one another and no translation occurs within the data field between these key points. Therefore, the remainder of the j-directed axes (B/B', E/E', D/D' and the end key point) and all of the i-directed axes (end key point, A/A', B/B', C/C' and the other end key point) are used for development changes, i.e., gradient control. Note that a key point is not required at the intersection of an i-directed and a j-directed orientation axis as might be inferred from point B/B' in Figure 8.

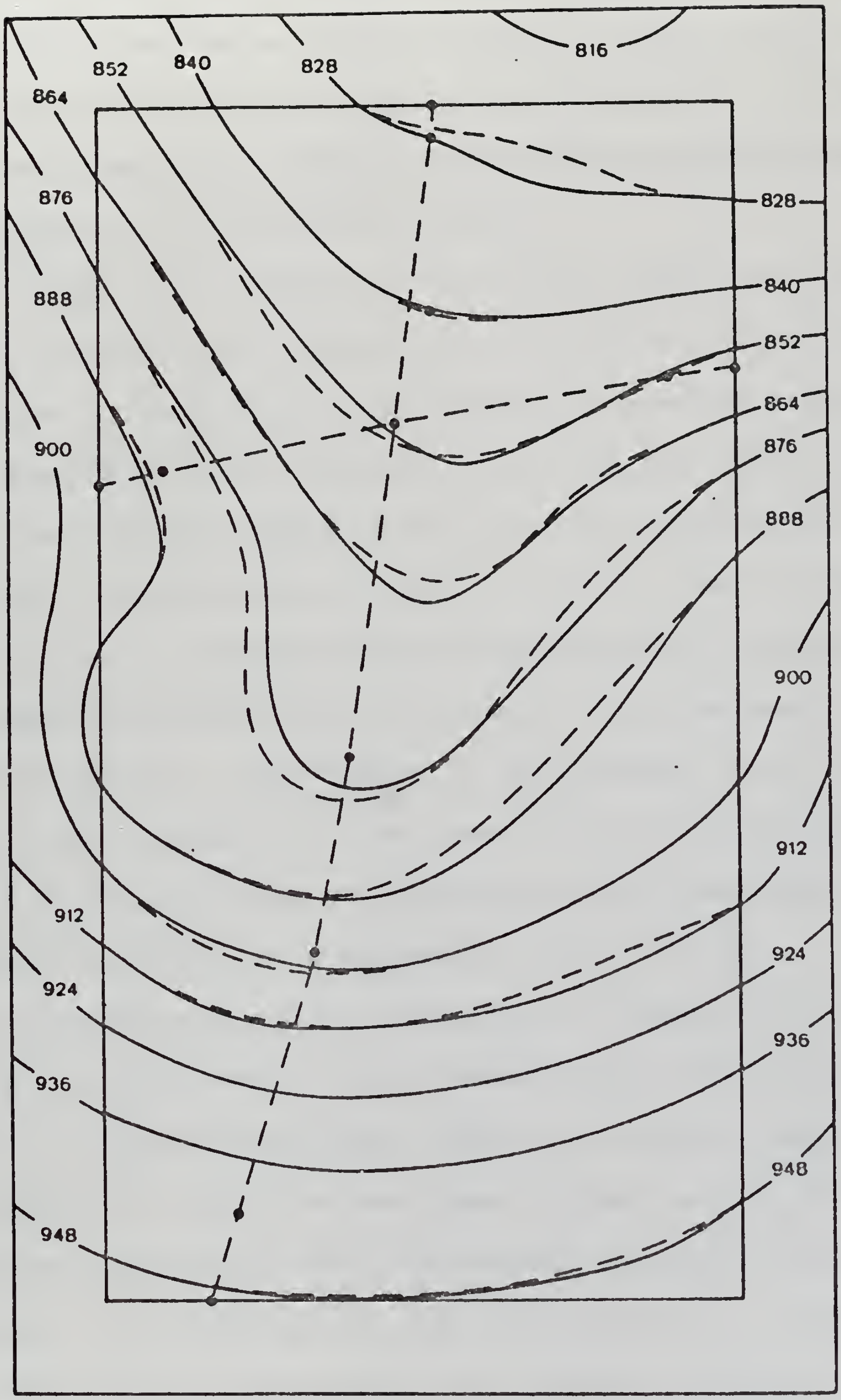
The third step in using this program is the determination of the values of development desired. Development is specified only at one or more of the observed orientation key points. That is, the primed lettered points in Figures 8, 10, 12, 14, and 16. By definition, development is the difference between the value of the parameter after translation and the final value in the numerically reanalyzed field. Since, in theory, simple translation will not change the value of any key point on the associated analyzed orientation axis, the value of development of any of these key points is simply the difference between the initial value and the final value in the manual reanalysis, when only one simple translation is performed. Values of development along the other orientation axis, when two observed axes are used, or values of development when oblique translation is involved must be calculated as the difference

between the value determined for the key point after translation and the value of the point in the manual reanalysis. Since this approach to the problem of numerical reanalysis uses a straight forward linear proportion for the changes established in the i-axis and j-axis translation, the final value of any key point after all translations have been accomplished may be quickly and accurately determined before the operation is performed on the computer. Therefore, one can always predetermine what this program will produce in each step of the computations. This simplicity is not obtainable when using bogus data in standard analysis programs.

The values of development used at 300 mb to reposition the trough and to properly delineate the axis of the jet stream are shown across the bottom of Figure 8. It should be remembered that the value of development is always set to zero by the program on the inner boundaries of the finite area.

Having determined the location of the finite area and the key points along with the desired values of development at the selected observed key points, this information is provided to the program for numerical reanalysis of the initial data field. In this case the continuous lines of Figure 9 result from the continuous lines of Figure 8.

The observed orientation axes and the dashed contours of the manual reanalysis shown in Figure 8 are reproduced in Figure 9 for the convenience of the reader. By comparing the continuous contours with the dashed contours



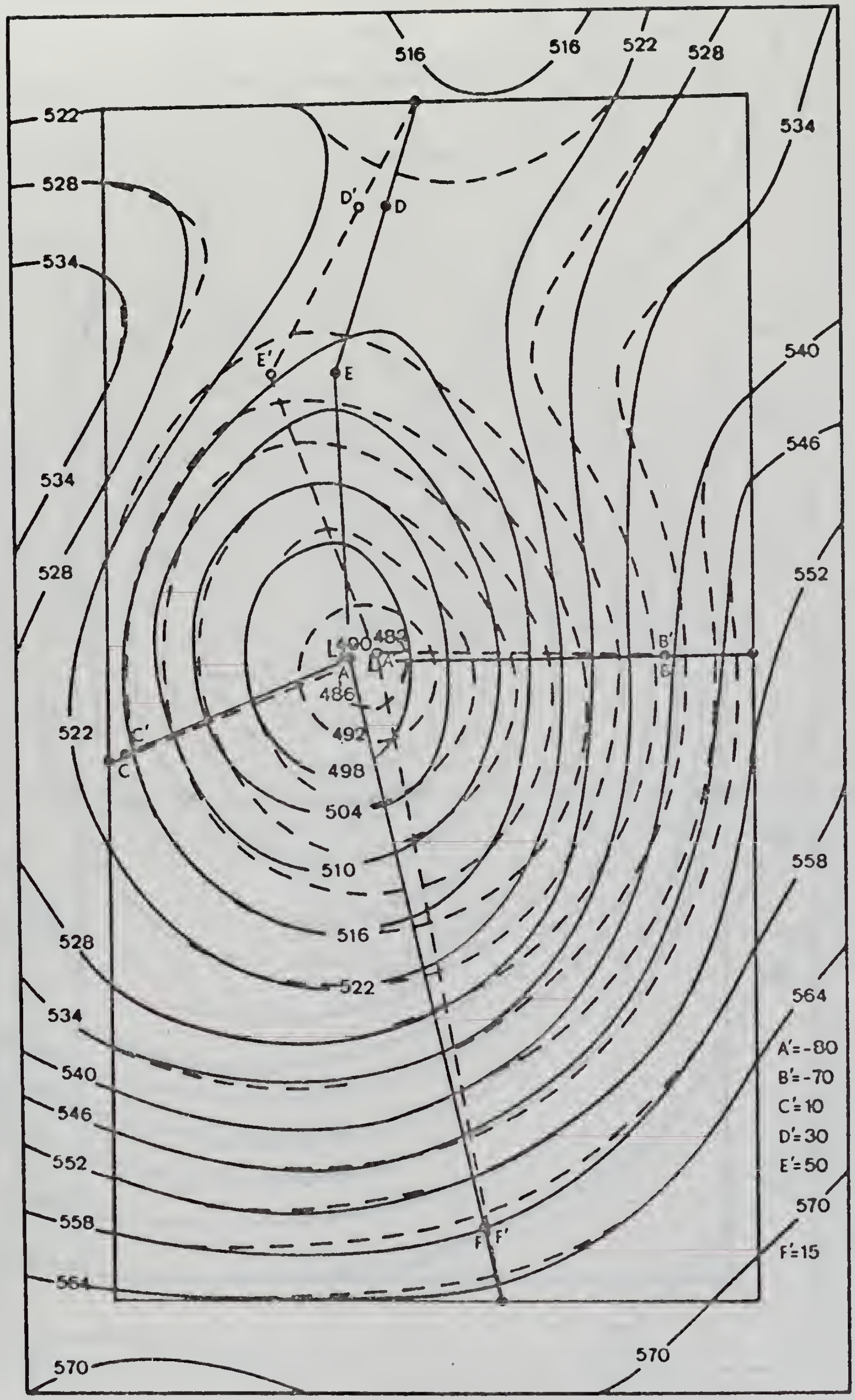
——— NUMERICAL REANALYSIS ------ MANUAL REANALYSIS

Figure 9. 300 MB HEIGHTS: NUMERICAL REANALYSIS AND MANUAL REANALYSIS

of Figure 9 one can evaluate how well the numerical reanalysis reproduces the essential features of the manual reanalysis. As can be readily seen, the trough and jet stream have been accurately repositioned and delineated without the appearance of sub-scale "noise."

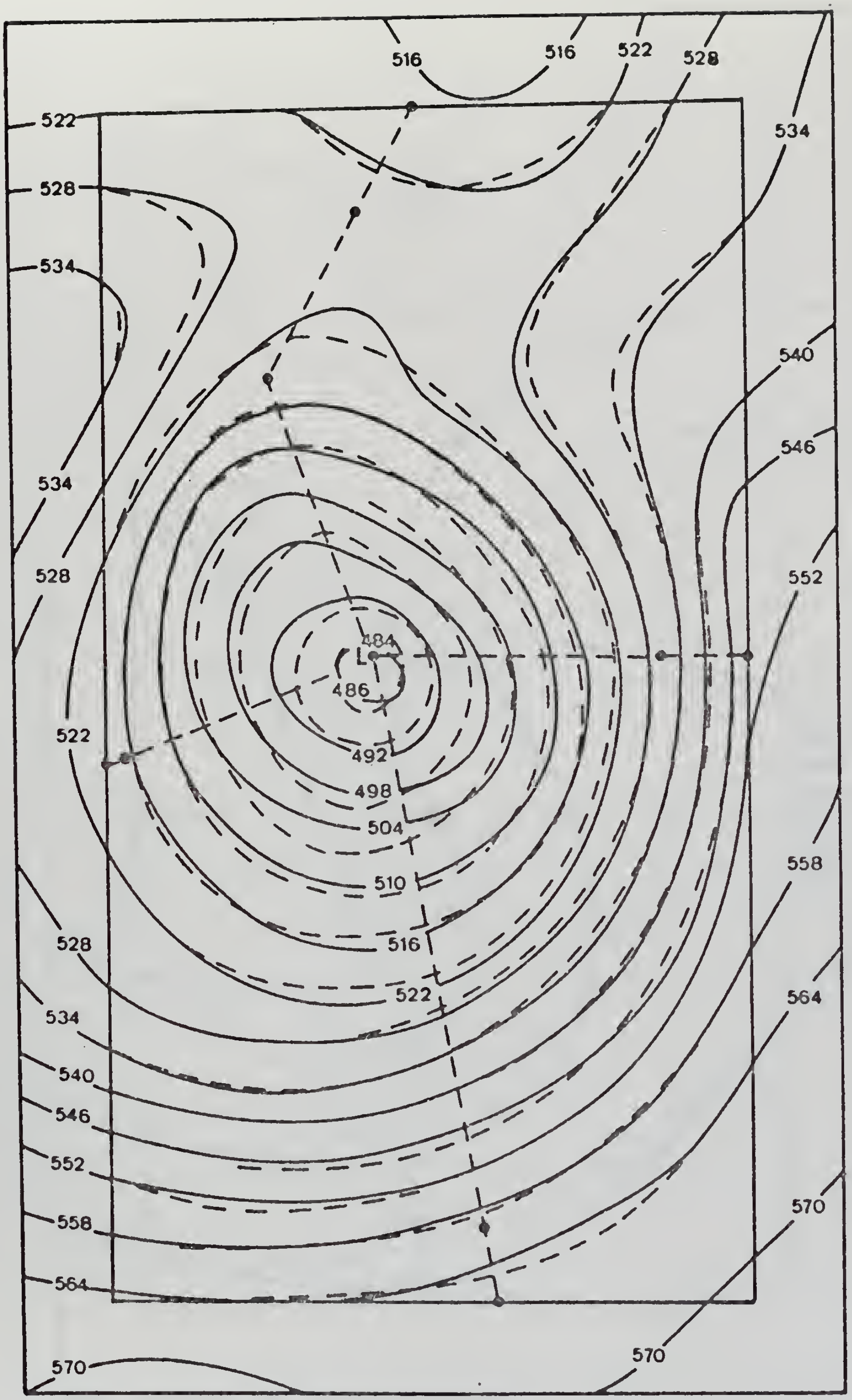
An example of changes at the 500 mb level are illustrated in Figures 10 through 13. The 500 mb height field of Figure 10 requires only a slight translation but extensive changes in the magnitude of the heights (development). As can be seen in Figure 10 the orientation axes are simple with only the central key points A and A', and the key points E and E' required in the interior for translation. The other key points are used solely for development or gradient control. The values of development used with the cyclone are indicated in the lower right of Figure 10. Figure 11 demonstrates the success of this numerical reanalysis program with a deepening cutoff cyclone.

The changes required in the 500 mb temperature field, Figure 12, are somewhat more complex than the changes required in the 500 mb height field. The center point B, key points E, F and the associated primed points on the observed orientation axis are requied to adjust the pattern through translations while the key points A, C, D, and G are required for development and gradient control. The actual values of development used in this example are depicted on the right side of Figure 12. The resulting temperature pattern shown in Figure 11 is close to the desired



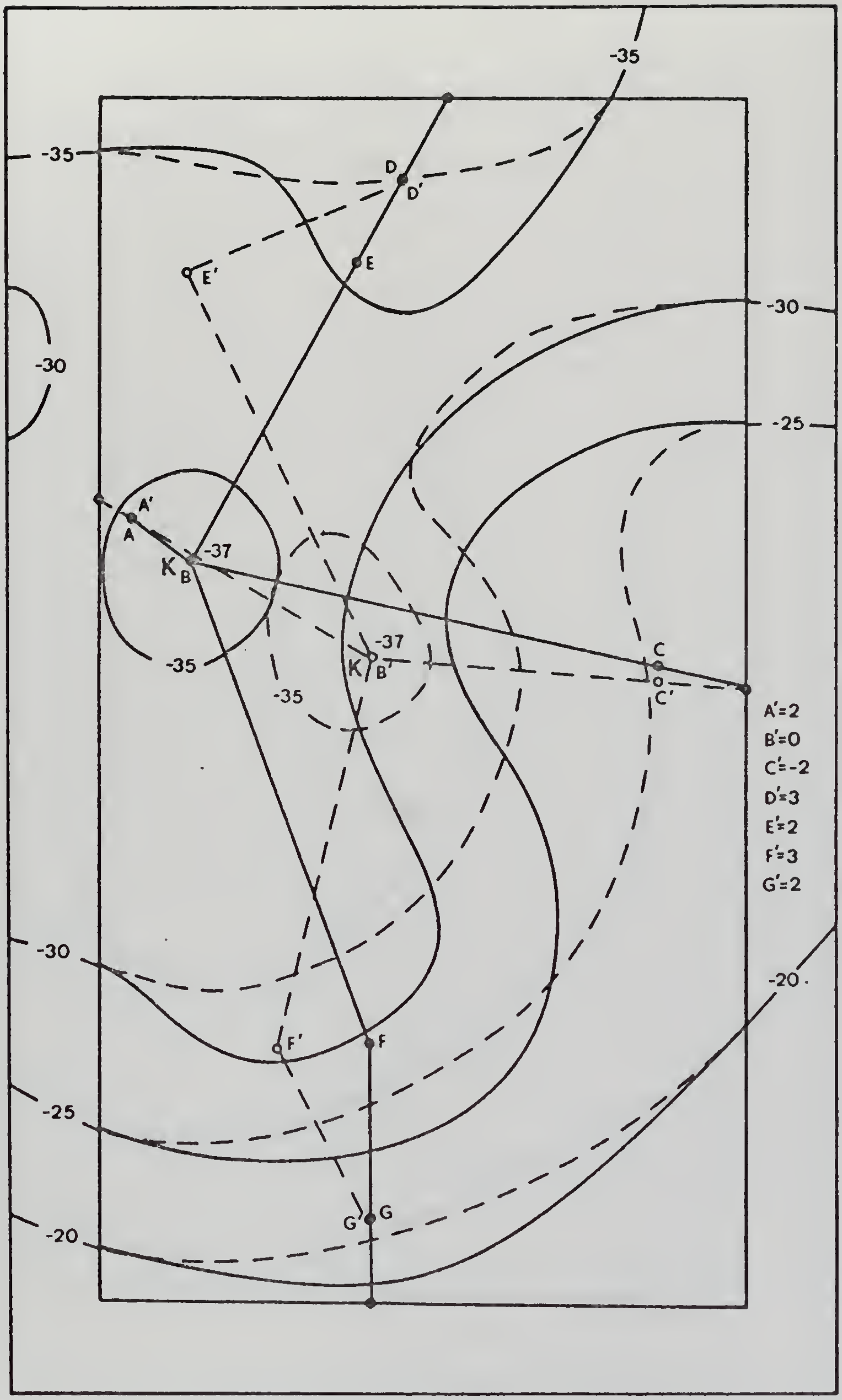
——— NUMERICAL ANALYSIS ------ MANUAL REANALYSIS

Figure 10. 500 MB HEIGHTS: NUMERICAL ANALYSIS AND MANUAL REANALYSIS



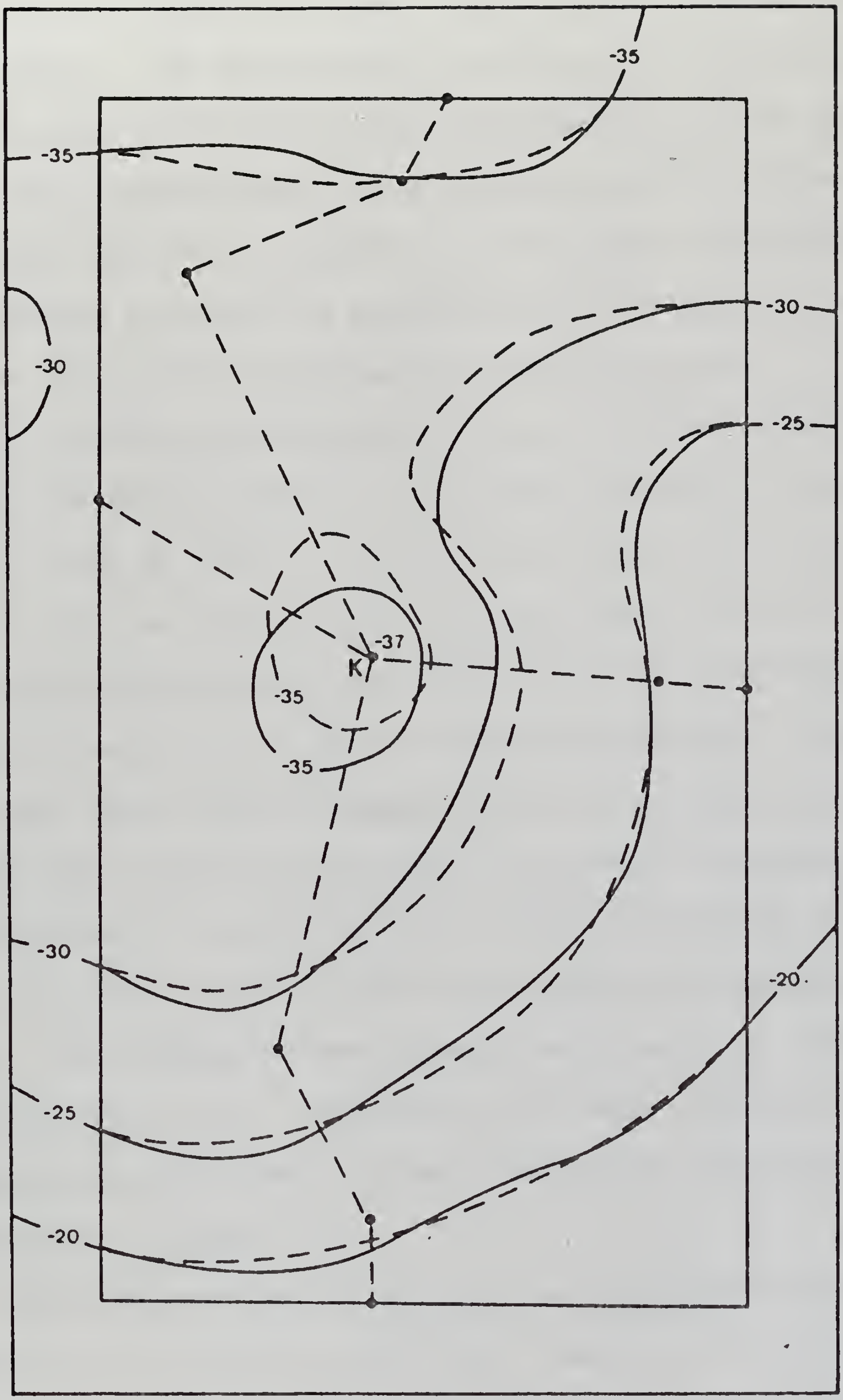
——— NUMERICAL REANALYSIS ------ MANUAL REANALYSIS

Figure 11. 500 MB HEIGHTS: NUMERICAL REANALYSIS AND MANUAL REANALYSIS



——— NUMERICAL ANALYSIS ------ MANUAL REANALYSIS

Figure 12. 500 MB TEMPERATURES: NUMERICAL ANALYSIS AND MANUAL REANALYSIS



——— NUMERICAL REANALYSIS ------ MANUAL REANALYSIS

Figure 13. 500 MB TEMPERATURES: NUMERICAL REANALYSIS AND MANUAL REANALYSIS

pattern, but could have been improved with the use of more key points. The meteorologist working in quality control must decide if the additional information in the sparse data area warrants very fine control of the pattern and gradients within the pattern, or if only a rough idea of the overall pattern and gradients are available. He should strive not to over-analyze the available data.

The concluding examples of this numerical reanalysis scheme are illustrated in Figures 14 through 17, and are on the 1000 mb level. The 1000 mb heights are shown in Figure 14. As can be seen in this figure, there is rather an extensive pattern change indicated and considerable height rises for the 1000 mb pressure surface. It should be noted that rather large changes are called for in the lower right corner of the grid in view of the proximity of the boundary. It is also noted that only three interior key points are used to guide the numerical reanalysis program. The values of development are listed in the lower left of Figure 14. Considering the many facets of this example the reanalysis scheme does surprisingly well, as indicated in Figure 15.

The modification of the 1000 mb temperature pattern, Figure 16, is the most difficult numerical reanalysis problem of the series, requiring extensive changes to the overall pattern and the creation of a closed center of cold air. The choice of key points in this case clearly illustrates the fact that key points need not be on an actual trough or

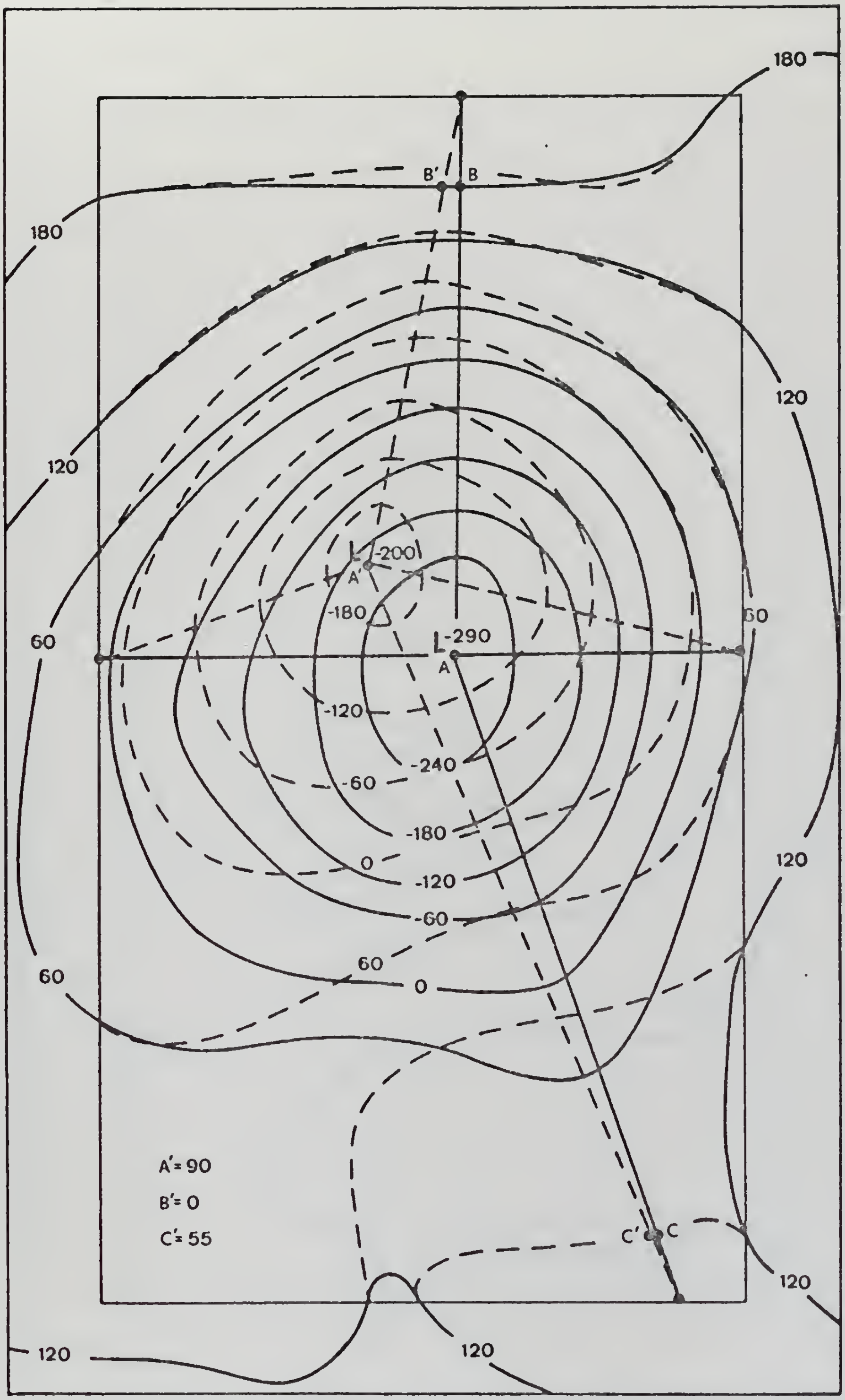


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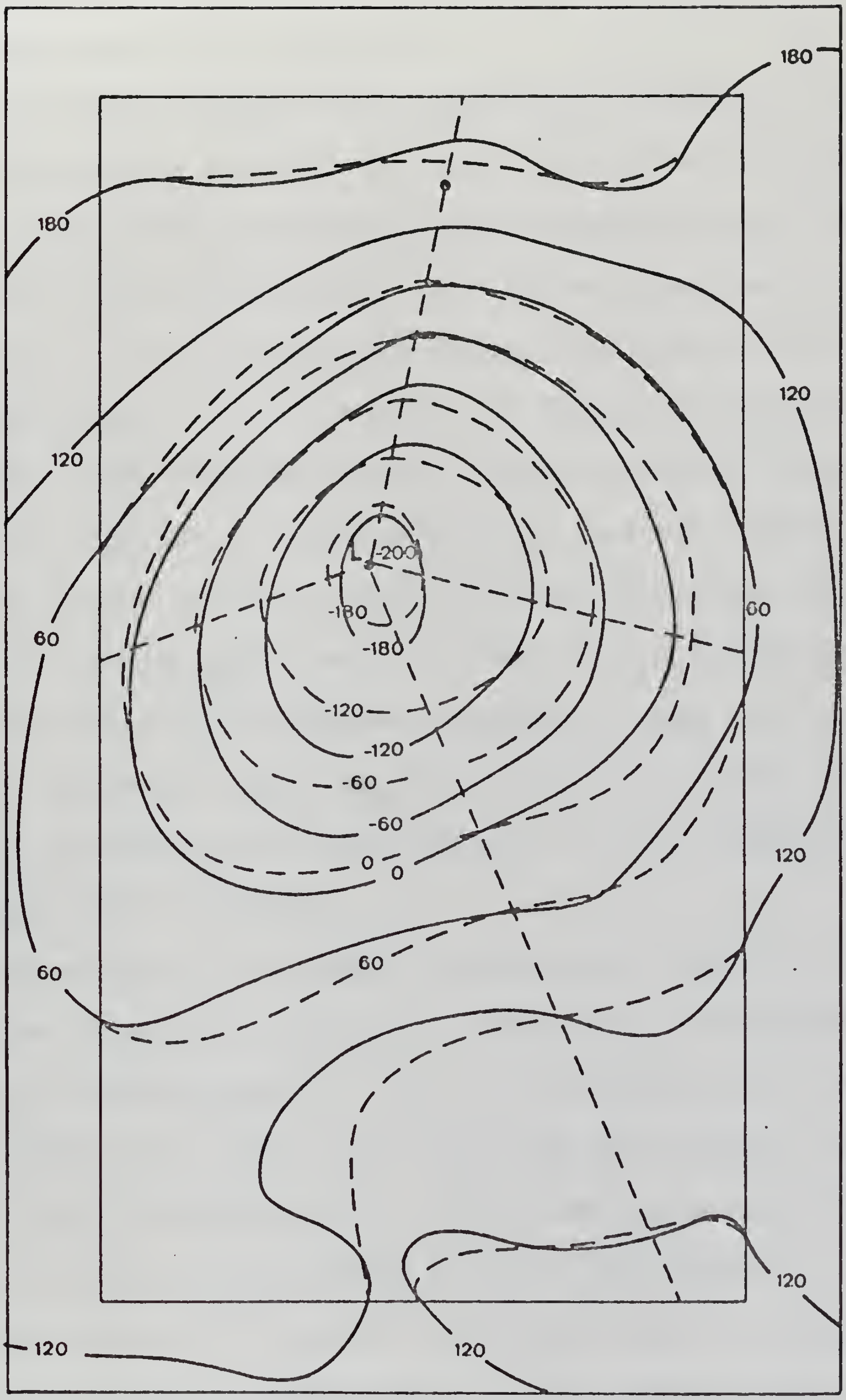
Figure 14. 1000 MB HEIGHTS: NUMERICAL ANALYSIS AND MANUAL REANALYSIS



——— NUMERICAL REANALYSIS ------ MANUAL REANALYSIS

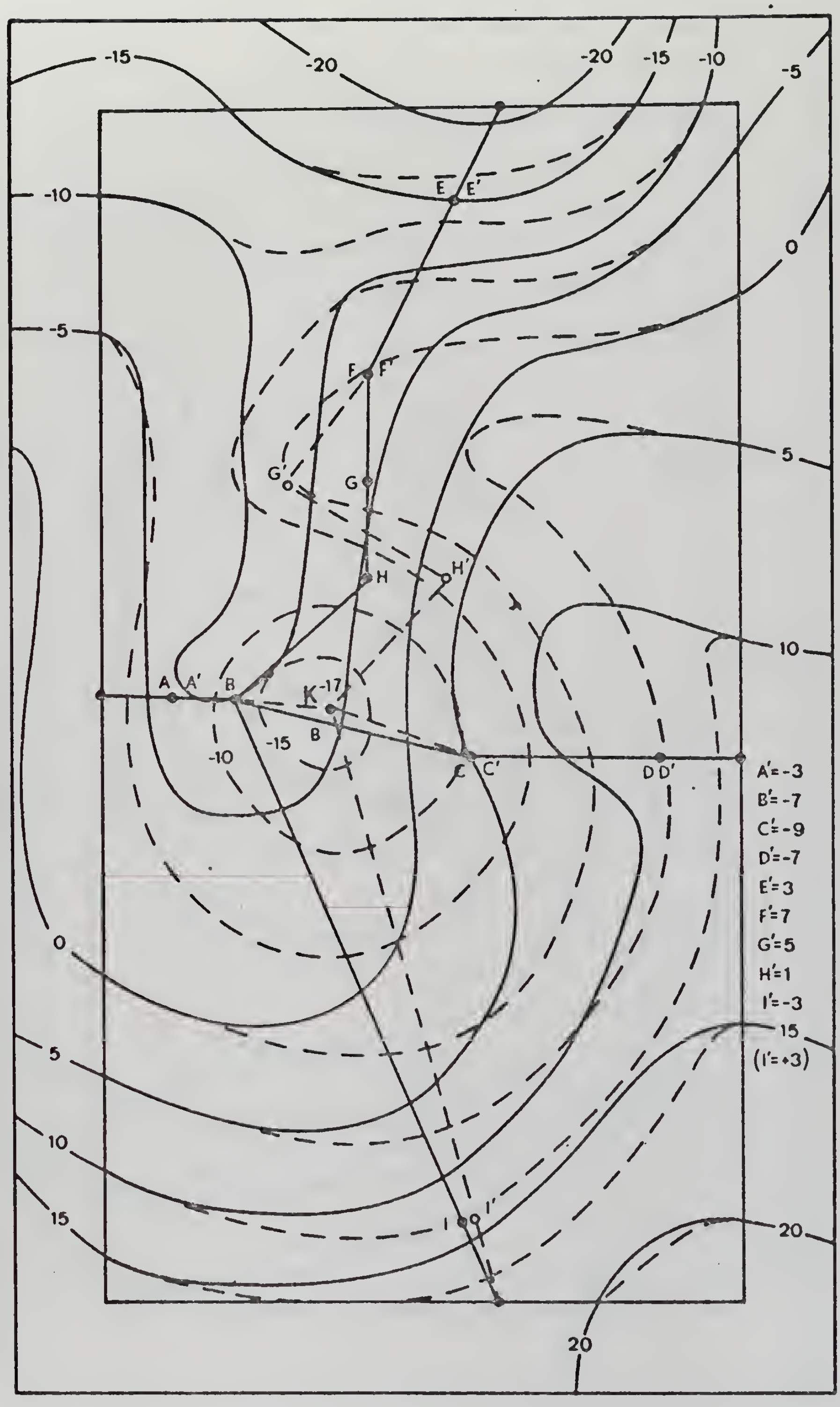
Figure 15. 1000 MB HEIGHTS: NUMERICAL REANALYSIS AND MANUAL REANALYSIS

ridge axis, and in some cases cannot be if the desired modifications are to be achieved.

The extreme protrusion of warm air required in the modification of the upper poriton of the figure could not have been accomplished with development changes alone. Note that the i-axis translation is both positive and negative (G to G'). The required development is given on the right side of Figure 16. The results in Figure 17 show how well the above modifications worked. The extreme protrusion of warm air required in the new pattern and the marked cooling between points C and D resulted in the corollary development of a small warm center because of the proportional manner in which this program spreads changes in the data field. However, the difference between the sharp protrusion and the closed center would probably not be significant in an operational analysis.

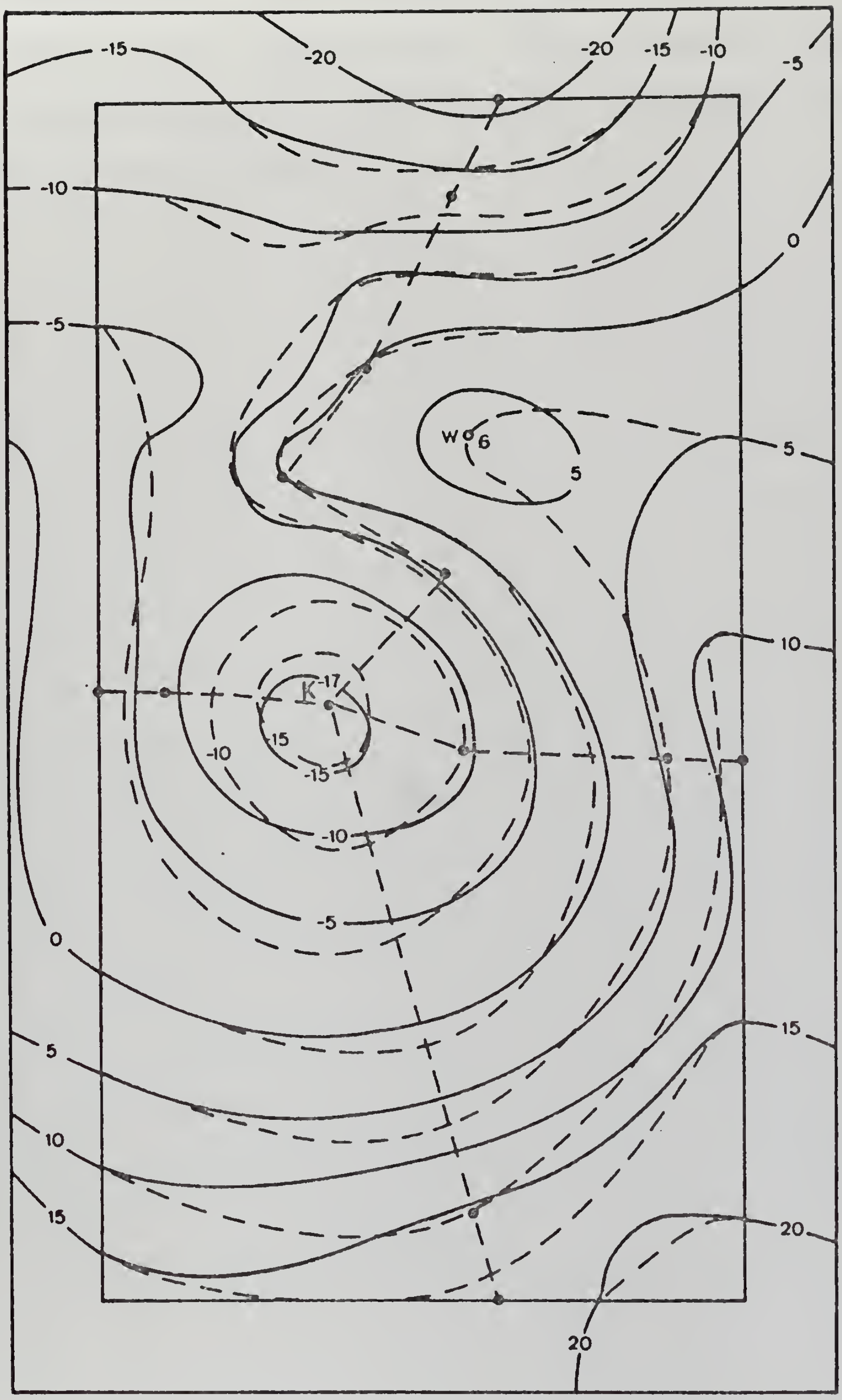
The effect of a mistake in entering values of development can be seen in Figure 17. The value of development required for key point I' is -3°. The minus sign was inadvertently left off so the value of development actually used in the program is +3°. This results in the slight ridging effect in the vicintiy of I' in Figure 17.

This series of figures illustrates that the degree of accuracy desired is determined by the number of key points chosen to establish the changes to be effected by this program. The complexity of the reorientation of the pattern



——— NUMERICAL ANALYSIS ------ MANUAL REANALYSIS

Figure 16. 1000 MB TEMPERATURES: NUMERICAL ANALYSIS AND MANUAL REANALYSIS



——— NUMERICAL REANALYSIS ------ MANUAL REANALYSIS

Figure 17. 1000 MB TEMPERATURES: NUMERICAL REANALYSIS AND MANUAL REANALYSIS

and orientation of the various axes also bears heavily on the number of key points used. These examples have, however, demonstrated that the program is flexible and yet simple and easy to use.

IV. CONCLUSIONS

A significant aspect of this method is that the position and orientation of cyclones, anticyclones, troughs, ridges and jet streams is guaranteed in this method of numerical reanalysis, and no such statement can be made with the operational use of bogus data in the standard analysis programs. The information which is directly interpretable from video and infrared imagery is the position and orientation of cyclones, troughs, ridges, jet streams and anticyclones, and not quantitative values of bogus data at the numerous points required in conventional analysis programs. This reanalysis scheme concentrates on the information which can be most reliably taken from this type of satellite data and minimizes the use of bogus data values which must be inferred from statistical regression equations, space continuity, time continuity and dynamical constraints.

This scheme appears to be easier and faster to use than the current operational procedures using bogus data. In additon, the quality control meteorologist knows exactly what the pattern and central or key values will be with this method of numerical reanalysis.

Based upon this preliminary research, this numerical reanalysis scheme appears to offer an operational method of improving the "update analysis", the "first guess field" or both of these fields, until quantitative soundings of the atmosphere are routinely available over a dense network of

data points from satellite-borne instruments. The "update analysis" is the last analysis performed by a numerical center for a given synoptic time and, for the upper-air analysis, the "first guess field" is essentially a twelve-hour prognosis based on the "update analysis."

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3. ABSTRACT

A new approach to numerical analysis is presented. Instead of providing conventional data one essentially prescribes the desired pattern and the analysis is performed through proportional differences.

If satellite or other data indicate a synoptic system in a numerical analysis should be reanalyzed, a three-dimensional manual analysis is performed. Particular attention is given to the adjustment of the location and orientation of the synoptic pattern. No changes are permitted on the borders of the finite area containing the synoptic system.

Orientation axes for the patterns of the numerical and manual analyses are defined by sets of key points. Using the space difference between these orientation axes, the boundaries and the amount of development specified at the key points this scheme guarantees a reanalysis which smoothly blends with the original analysis and retains the new location and orientation of the synoptic system.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Numerical Weather Analysis Meteorological Satellite Observations 1000 mb, 500 mb, and 300 mb Analysis						

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